

## 6 Contaminant Fate and Transport

This section summarizes processes that may affect concentrations of sediment contaminants. The status of source control efforts within Bellingham Bay is discussed. Also discussed are the processes that may improve site sediment quality (e.g., sediment natural recovery) and those processes that can degrade sediment quality or trigger sediment recontamination. The contaminant fate and transport topics covered in this section include the following:

- Sediment Source Control Activities (Section 6.1)
- Natural Recovery Processes (Section 6.2)
- Other Factors Affecting Sediment Stability (Section 6.3).

### 6.1 Source Control Activities

Identification and control of sources of sediment contamination is a key objective of the SMS regulations. The RI/FS and Bellingham Bay Pilot activities have included significant source control evaluations and corrective actions. One of the drivers for implementation of the Log Pond Interim Remedial Action was to control secondary releases from this area to the other portions of the Site.

Site source control data have not identified any ongoing, significant sources of mercury, 4-methylphenol, phenol, or wood waste material to the Whatcom Waterway Site area. A summary of the source control information is provided below.

#### 6.1.1 Control of Historical Contaminant Sources

The primary sources of sediment contamination within the Whatcom Waterway Site are historical in nature. These historical sources have been controlled through changes in practices and through pollution control improvements.

- **Chlor-Alkali Plant Wastewaters:** Wastewater discharges from the GP Chlor-Alkali Plant operations were the primary source of elevated mercury concentrations within the Whatcom Waterway Site sediments. As described in Section 2.2.1, the main period of mercury release was between 1965 and 1971 when mercury-containing wastewaters from the Chlor-Alkali Plant were discharged directly into the Log Pond. Between 1971 and 1979 pretreatment measures were installed to reduce mercury discharges. Chlor-alkali plant wastewater discharges to the Log Pond area were discontinued in 1979 after the ASB facility was constructed and put into operation. The Chlor-Alkali Plant operations were terminated in 1999 and the plant was subsequently

demolished. Demolition of the Chlor-Alkali Plant terminated this source of mercury-containing wastewaters.

- **GP Mill Wastewater:** Since 1979 the wastewater and stormwater from the GP mill site have been discharged via the GP ASB secondary treatment system and associated outfall, consistent with operating requirements of the facility NPDES permit. Pollution controls and corrective actions implemented under the NPDES program dramatically reduced organic loadings to the Whatcom Waterway area, reducing sources of phenolic compounds to site sediments. Wastewater loadings to the GP wastewater system have also decreased dramatically due to the closure of the pulp mill, the chemical plant, and the Chlor-Alkali Plant. The combined wastewater and cooling-water flows from the remaining tissue mill operations and from the adjacent Encogen co-generation plant average less than 20 percent of the previous daily flows. The organic and inorganic composition of the wastewater stream has also improved significantly. Sediment monitoring, wastewater monitoring and source control analyses have been performed as part of the NPDES monitoring requirements. Source control analyses summarized in the 2000 Whatcom Waterway RI/FS indicated that the outfall would not result in sediment contamination in the area around the outfall. Sampling data from 1999 confirmed model predictions and demonstrated that the sediments within the vicinity of the G-P outfall comply with SQS cleanup criteria for mercury. Biological confirmatory tests were run on the samples from the three highest-concentration stations in the station cluster. All biological tests passed SQS biological screening criteria. Therefore, the confirmatory biological testing procedures under SMS do not qualify this station cluster as a contaminated sediment site and demonstrates compliance with the SQS criteria.
- **Wood Products Handling and Log Rafting:** In addition to the GP pulp and tissue mill operations, historical land uses in the Whatcom Waterway area included extensive wood products manufacturing activities, including lumber and shingle mills, box factories, and log-yard operations. Extensive portions of the harbor area were historically leased from the State of Washington for log rafting operations. Since that time there have been extensive changes in the Bellingham economy and the types of industrial activities on the waterfront that have resulted in closure of the wood products mills and termination of log rafting operations. In addition, Ecology has developed best management practices for log yard operations, and protocols have been developed to reduce wood debris release from in-water handling of logs and log

bundles. These changes have combined to largely eliminate the release of new wood waste or woody debris within the Whatcom Waterway Site area.

- **Improvements in Waterfront Construction Practices:** Some of the detected PAH and semivolatile organic compound contamination in sediments in GP and Bellingham Shipping Terminal wharf areas appears to be associated with the historical use of pilings treated with creosote and pentachlorophenol preservatives. More recent construction activities have favored the use of concrete or metal pilings where practicable to reduce potential water quality and sediment impacts and improve overall project design performance and usable life.

### **6.1.2 Other Stormwater and Industrial Discharges**

Stormwater discharges are a potential source of water and sediment contamination to the bay and the city is regulated under Phase II of the federal NPDES Storm Water Program. The City of Bellingham stormwater program, along with other permitted discharges described in the Inner Bellingham Bay Sediment TMDL, are described below. A total of 40 waterfront or surface water discharge source locations to the bay were identified. The potential sources included 10 waterfront NPDES discharges, 12 suspected or confirmed contaminated sites, and 18 city storm water outfalls. However, no ongoing sources have been identified that have the potential to affect water or sediment quality beyond the immediate discharge zone. A summary of the main identified stormwater and wastewater discharges is provided below:

- **City of Bellingham Stormwater System:** The City of Bellingham originally developed a local stormwater program and submitted it to the Department of Ecology in 1999. It included an extensive source cleanup program, which incorporated vector truck waste activities. After review of the program, Ecology recommended that the city concentrate on improvements in following two areas: 1) coordinate the stormwater program with the planned sediment cleanup in Bellingham Bay; and 2) improve the stormwater plan requirements for redevelopment. Bellingham is also a “Phase II” city in the federal stormwater NPDES permitting program, which requires stormwater programs meeting the federal requirements to be in place (Ecology, 2001).
- **Port of Bellingham Stormwater Program:** The Port leads environmental protection efforts at its properties around Bellingham Bay. As part of this role, the Port recently created a Stormwater Master Plan for Squalicum Harbor. The Plan conforms to the City of Bellingham’s stormwater requirements as well as the Department of Ecology’s Puget Sound Stormwater Technical

Manual for all development and redevelopment activities in the Harbor. The Stormwater Master Plan includes a series of pollution prevention operational and structural BMPs and treatment alternatives to reduce or eliminate adverse impacts from Port activities on stormwater and receiving waters. The planned efforts for Squalicum Harbor and Marina are intended to provide a model for Port source control activities throughout Bellingham Bay. The Port also carries three baseline general stormwater NPDES permits for facilities that drain to or otherwise potentially impact Bellingham Bay. One general permit is for the Bellingham Airport. The Port also has coverage for the maintenance shop near the shipping terminal on Whatcom Waterway and for the Alaska ferry terminal in Fairhaven. Data for these facilities covered under the general permit does not show they are a source of sediment contamination (Ecology, 2001).

- **C-Street Combined Sewer Overflow (CSO):** The C Street CSO is regulated under the Bellingham Post Point NPDES Permit (No. WA-002374-4). Post Point is the location of the city's Waste Water Treatment Plant (WWTP). Department of Ecology records show that there have been three CSO overflow events since 1995. However, the City has made substantial system improvements in recent years to minimize overflow events. In addition the C Street stormwater discharge was identified as an outfall of concern in the development of the City of Bellingham Comprehensive Stormwater Program and under the NPDES general stormwater program.
- **Bornstein Seafoods:** Bornstein Seafoods carries a State Waste Discharge Permit (ST7304) for the discharge of screened seafood processing wastewater to the Bellingham Post Point WWTP. They have a Baseline General Permit for Industrial Stormwater (SO3-000679). The Department of Ecology administers both permits. Bornstein Seafoods is not identified as an ongoing source of contaminated sediments (Ecology, 2001).

### **6.1.3 Other Area Cleanup Sites**

Ecology is conducting cleanup activities at a number of sites located adjacent to the Whatcom Waterway Site, including the following:

- **I&J Waterway:** The results of Whatcom Waterway RI/FS studies performed in 1996 and 1998 demonstrated that surface sediment impacts were present in certain nearshore locations of the I&J Waterway, but that these impacts were primarily associated with contaminants different than those of the Whatcom Waterway sediments. Later studies performed in 2001 confirmed that the

surface sediment impacts were predominantly associated with elevated bis(2-ethylhexyl)phthalate and nickel in a localized area adjacent to the Bornstein Seafoods facility and the former Olivine lease area, respectively. The sources of these compounds appear to be historical events, including the destruction of the seafood processing plant by fire in 1985, and historical Olivine dust and wastewater discharges from the ore crushing plant during the 1960s, 1970s, and 1980s. Ecology and the Port have entered into a legal agreement for completion of a sediment RI/FS study. The RI/FS is scheduled to be released for public review during late 2006.

- **Cornwall Avenue Landfill:** The Cornwall Avenue Landfill site, located at the south end of Cornwall Avenue, measures approximately eight acres and is adjacent to Bellingham Bay. Most of the site was originally tide flats and sub-tidal areas of Bellingham Bay. From 1888 to 1946, the site was used for sawmill operations, including log storage and wood disposal. From 1946 to 1965, the Port of Bellingham held the lease on the state-owned land. The property was subleased to the City of Bellingham from 1953 to 1962. The City used the Site for municipal waste disposal. The City continued waste disposal at the site under a sublease from American Fabricators from 1962 until 1965. Landfill operations ended at the Site in 1965, and a soil layer was placed on top of the municipal waste (Ecology, 2004a). Previous environmental investigations of the site indicate the presence of hazardous substances in groundwater, surface water, soil and sediments above state cleanup standards. These substances include arsenic, copper, lead, mercury, silver, zinc, cyanide, polychlorinated biphenyls (PCB), bis(2-ethylhexyl)phthalate, polycyclic aromatic hydrocarbon (PAH) compounds and fecal coliform. The Port is leading the completion of an RI/FS for cleanup of this site in coordination with the City and DNR. The completion of this study is expected during 2006 and will include remediation measures for impacted uplands and nearshore sediments. Ecology is ensuring that cleanup activities are appropriately coordinated with the adjacent RG Haley site.
- **RG Haley:** Soil and groundwater at this upland contaminated site contain concentrations of pentachlorophenol, petroleum and associated constituents that exceed water quality and sediment protection criteria, respectively. In 2001, an oil seep was observed discharging into Bellingham Bay from the shoreline along the northern boundary of the site. An investigation revealed that portions of the site were contaminated with chemicals consistent with the site's former use as a wood treatment facility. The

contaminants were found at levels exceeding state regulatory cleanup levels in surface water, shallow groundwater, sediment and soil (Ecology, 2004a). The visible release of contamination from the site into Bellingham Bay was controlled through the installation of a barrier wall and a product recovery system. The temporary contaminant recovery system continues to operate. An RI/FS is being conducted under an Agreed Order with Ecology and a draft report is scheduled to be released for public review during 2006. The cleanup at this site will include remediation of impacted uplands and nearshore sediments. Ecology is ensuring that cleanup activities are appropriately coordinated with the adjacent Cornwall Avenue Landfill site.

- **Holly Street Landfill:** The Holly Street Landfill site is a 13-acre historic solid waste landfill located in the Old Town district of Bellingham. In the late 1800s, the site was part of the original Whatcom Creek estuary and mudflat. Around 1905, private property owners began filling portions of the site with dredge spoils and other materials to increase useable upland areas. From 1937 to 1953, municipal waste was used by owners to fill private tidelands within the former Whatcom Creek estuary. Wastes, including debris and scrap materials, were disposed of according to landfill disposal practices of the time (Ecology, 2004a). Solid waste covers approximately 9.1 acres on the northwest side of Whatcom Creek and 3.8 acres on the southeast side (Maritime Heritage Park). The City of Bellingham currently owns 8.3 acres of the 13-acre landfill site, including all landfill properties located along the Whatcom Creek shoreline (Ecology, 2004a). Refuse along the northern shoreline of Whatcom Creek was excavated in conjunction with construction of an engineered cap, and material will be placed along the southern shoreline to stabilize the bank. The northern shoreline excavation and cap system controls releases of copper and zinc to Whatcom Creek that occur when estuary water mixes with the solid waste in the bank. The cleanup also included long term protection through legal restrictions on property use and monitoring of the cleanup action. Excavation for the project removed approximately 12,400 tons of solid waste, primarily from the northern bank prior to constructing the cap with clean materials (Ecology, 2004a).
- **Central Waterfront Site:** The Central Waterfront site includes four former cleanup sites that have been combined into a single site to comprehensively manage commingled groundwater contamination. The site includes properties formerly known as the Roeder Avenue Landfill, the Chevron Bulk Fuels Facility, The Boat Yard at Colony Wharf, and the Olivine Uplands site (Ecology, 2004a). The

Roeder Avenue Landfill was a bermed municipal landfill operated between 1965 and 1974. The Chevron Bulk Fuels Facility is located along C-Street and is an area where soils and groundwater are impacted by petroleum hydrocarbons associated with historic fuel handling practices. This has been purchased by the Port of Bellingham. The Boatyard at Colony Wharf is an operational boatyard. Soils and groundwater at the site are impacted by low levels of metals contamination, principally copper. Petroleum has also been detected in soil and groundwater. The site has been purchased by the City of Bellingham, and cleanup activities are being managed by the Port under an Interlocal Agreement with the City. The Olivine site was formerly used by previous Port tenants for operation of a lumber mill, and later for operation of a rock crushing plant. Contaminants identified at the site include petroleum hydrocarbons, polynuclear aromatic hydrocarbons, and low levels of heavy metals, principally nickel. The Port and City are conducting the cleanup of the Central Waterfront site and expect to complete an uplands RI/FS for public review in early 2007 under an Agreed Order with Ecology.

- **Chlor-Alkali Plant Site:** The Chlor-Alkali Plant site was recently acquired by the Port from GP. Soils and groundwater at that site contain elevated levels of mercury from historic operations of the Chlor-Alkali Plant by Georgia Pacific. Two rounds of RI/FS investigations have been performed at the site, and additional studies were performed as part of the Whatcom Waterway Log Pond Interim Action. Results indicate that soil and groundwater conditions at the site do not represent a current source control concern for Whatcom Waterway site sediments or surface water quality. The Port, GP, and Ecology plan to amend an existing Agreed Order to complete an RI/FS of this site.
- **Former GP Pulp and Tissue Mill Site:** The Pulp and Tissue Mill site was also recently acquired by the Port from GP. This property has been used since the early 1900s for pulp and tissue mill operation. Some impacts to soil and groundwater were identified at the site during environmental investigations performed at the site during 2004, and the site was listed by Ecology as a contaminated site. The key issues at the site include petroleum contamination near old bunker fuel storage areas, and low-level metals impacts in groundwater near the former acid plant area of the pulp mill. Based on patterns of sediment contamination in the Whatcom Waterway, neither of these areas appears to represent an ongoing source of contamination to Whatcom Waterway sediments. However, additional actions will be required to address these contamination problems and finalize plans for site cleanup and redevelopment of

the Pulp and Tissue Mill site. Under the terms of the GP property acquisition, the Port will conduct the investigation and cleanup of this site, with oversight by the Department of Ecology.

## **6.2 Natural Recovery Processes**

Natural recovery of aquatic sediments can occur through physical processes, biological processes, and chemical processes. Natural recovery is defined as the effects of natural processes that permanently reduce risks from contaminants in surface sediments (Apitz et al., 2002) and effectively reduces or isolates contaminant toxicity, mobility, or volume. At the Whatcom Waterway Site, natural recovery through the physical process of sediment deposition has been highly effective at restoring sediment quality in the bioactive zone throughout much of the Whatcom Waterway Site.

The potential for natural recovery of sediment is determined through multiple lines of evidence. A thorough assessment of natural recovery was performed as part of the 2000 RI/FS (Hart Crowser and Anchor Environmental, 2000). That work is summarized below, including measurements of sediment profiles, estimates of deposition rates, and the findings of natural recovery modeling. In addition to the work summarized in the 2000 RI/FS, the performance of natural recovery was empirically demonstrated through the improvement in sediment conditions that occurred between the 1996/1998 and the 2002 sediment monitoring events.

### **6.2.1 Measured Sedimentation Rates**

Sedimentation studies were completed as part of the 1996 investigation activities, as summarized in the 2000 RI/FS.

#### **Sedimentation Studies**

As part of the RI/FS sampling effort, three natural recovery cores (HC-NR-100, HC-NR-101, and HC-NR-102) were collected and two sediment traps (HC-ST-100 and HC-ST-101) were deployed and sampled within the study area. Sediment traps HC-ST-100 and HC-ST-101 were co-located with natural recovery cores HC-NR-100 and HC-NR-101, respectively; the traps were deployed for three periods, each approximately four months in duration. Sampling locations are shown on Figure 3-4.

The natural recovery cores were sectioned in approximately 2 cm increments as described in the approved Sampling and Analysis Plan (SAP; Hart Crowser, 1996a). Selected subsamples were submitted for isotopic analysis of lead-210 (Pb-210), and cesium-137 (Cs-137), and chemical analysis of total mercury, and total solids. Data from the natural recovery cores were used to estimate the net sedimentation rates in the study area, and to evaluate mercury concentration trends through time (Table 6-1).



Sediment traps were deployed, retrieved, and sampled to characterize settling particulates. Settled particulate matter (SPM) that had accumulated in the traps was analyzed for total mercury, phenols, TOC, and total solids. Data from the sediment trap study were used to estimate gross sedimentation rates, and to characterize the chemical and physical properties of SPM in the study area. In addition, comparison of gross sedimentation rates in sediment traps with net sedimentation rates in co-located, radio-dated cores provides an estimate of resuspension rates.

The gross sedimentation rate (settling rate, see Table 6-2) was estimated from sediment trap data and provide a measurement of the flux of suspended solids through the water column. The net sedimentation rate (Table 6-2) was estimated from sediment cores dated with radioisotopes (Cs-137 or Pb-210) or chemical tracers which can be correlated with specific historical events (i.e., mercury in Bellingham Bay). Net sedimentation describes the rate at which sediments are permanently incorporated into the seabed. The difference between gross sedimentation rates and net sedimentation rates provides information on the rate at which bottom sediments are resuspended to the overlying water column where they may be subject to horizontal advection or resettling.

Sediment in the natural recovery cores has been subjected to both coring-induced compaction (an artifact of the sampling process) and burial-induced compaction (the natural consolidation of sediments). The effect of sampling induced compaction was removed from the data, and actual sampling depths were reconstructed based on the ratio of core penetration to core recovery.

Sedimentation rates are often presented in mass-based accumulation units of grams per square centimeter per year ( $\text{g}/\text{cm}^2\text{-yr}$ ) to implicitly account for burial-induced compaction and porosity reduction with depth in the sediment. However, the density gradients in the natural recovery cores are slight; therefore, sedimentation rate calculations were performed using length based units in centimeters per year ( $\text{cm}/\text{yr}$ ) without introducing significant errors. Length-based units were preferred for the following reasons: (1) the point of compliance for biological effects is defined on the basis of length, not mass, and is typically assumed to be the depth of the biological mixing zone (approximately 12 cm); and (2) length-based sedimentation rates are simpler, more intuitive, and more easily compared to geologic events in the sediment stratigraphy.

## **Net Sedimentation Rates**

An example of the measured profile of Pb-210 is presented on Figure 6-1. Net sedimentation rates can be calculated from Pb-210 activity based on a model of constant and uniform sediment accumulation (Battelle, 1995). Sediment accumulation rates, however, are affected by seasonal variations in sedimentation resulting from river discharges, vessel traffic, and biological

activities, as well as long-term variations resulting from changing land use patterns in the watersheds. Therefore, the interpretation of Pb-210 profiles is often subject to model assumption violations, particularly in shallow urban waterways such as inner Bellingham Bay. Non-uniform sedimentation probably accounts for much of the observed scatter in the profiles, although radioisotope counting errors also contribute to the uncertainty.

The supported Pb-210 activity for the natural recovery cores was estimated to be 0.75 disintegrations per minute per gram (dpm/g). This estimate is based on the range of published, supported Pb-210 values (0.5 to 1 dpm/g) typical for Puget Sound sediments (Battelle, 1995). An estimated value for the supported Pb-210 activity because a baseline Pb-210 value could not be established with certainty in the lower sections of the cores. The estimated supported value of 0.75 dpm/g is believed to be representative of Bellingham Bay conditions. Uncertainty associated with the supported Pb-210 values have very little effect on the calculation output, since the slope of the regression analysis drives the output.

The net sedimentation rate was calculated from the slope of natural logarithm of excess Pb-210 activity versus depth below the mixing layer. The slope was statistically determined using linear regression techniques. The estimated Pb-210 sedimentation rates ranged from 1.4 to 2.07 centimeters per year (cm/yr). These rates are generally consistent with sedimentation rates estimated using Cs-137 or mercury, as described below.

Cs-137 has entered the oceans over the last 55 years as the result of nuclear weapons testing. The peak in Cs-137 profiles is believed to reflect the major global input of Cs-137 to the earth's atmosphere during the period of active bomb testing, and is correlated with a date of 1962. An additional index depth is the point where Cs-137 concentrations begin to increase sharply from a background or non-detectable concentrations to measurable concentrations. This point can be time labeled because Cs-137 is anthropogenic in origin and no background concentrations occurred in sediments prior to the nuclear weapon testing. The depth representing the onset of the introduction of Cs-137 to the sediments is correlated with 1950. Figure 3-7 shows a profile including Cs-137 activity.

The sedimentation rates calculated from the Cs-137 profiles using both of the time indices (i.e., the onset and the peak of atmospheric fallout) were generally consistent between the natural recovery cores and ranged from 1.52 to 1.99 cm/yr based on the introduction of Cs-137 activity, and from 1.43 to 1.52 cm/yr based on the peak of Cs-137 activity. These sedimentation rates are generally consistent with the estimates derived using Pb-210 or mercury profiles. Modern sedimentation rates appear to be relatively stable, based on consistency across different datums, and thus are appropriate for use in future projections.

Selected subsamples from each natural recovery core were analyzed for total mercury. Mercury was selected as a chemical tracer because it is a primary constituent of concern in Bellingham Bay and the period of maximum discharge to the bay is well-documented. Maximum discharges of mercury to Bellingham Bay occurred between 1965 and 1970 (Bothner et al., 1980). Sediment mercury accumulations likely reached their maximum in approximately 1970, allowing a few years of lag time for mercury to flux through the water column and become incorporated in the sediment. Figure 6-1 includes a measured mercury profile. Estimated sedimentation rates based on the mercury profiles are generally consistent among the natural recovery cores and range from 1.54 to 1.98 cm/yr. These sedimentation rates are also consistent with estimates based on radioisotopic dating methods.

In summary, the average net sedimentation rates were calculated using the mean of the four estimation methods: (1) onset of Cs-137 activity, (2) peak of Cs-137 activity, (3) Pb-210 decay, and (4) peak mercury concentration. Average sedimentation rates calculated for inner Bellingham Bay are generally consistent among the three natural recovery cores and range from 1.52 cm/yr at HC-NR-100 and HC-NR-101 to 1.77 cm/yr at HC-NR-102. The uncertainty in the sedimentation rate estimates is about 0.5 cm/yr.

## **Gross Sedimentation Rates**

Gross sedimentation, or particle settling rate, is the sum of the net sedimentation and sediment resuspension. Gross sedimentation rates were determined by measuring the flux of particulate matter into sediment traps deployed about one meter above the seabed. Gross sedimentation rates are often higher than net sedimentation rates, because only a fraction of the particles settling through the water column are permanently incorporated into the seabed.

As part of the RI sampling program, two sediment traps (HC-ST-100 and HC-ST-101) were deployed in inner Bellingham Bay for three periods, each of approximately four months duration. The entire deployment period spanned from October 1996 to September 1997; however, sediment trap HC-ST-101 tipped over during the second deployment period and no sample was recovered.

Particle mass accumulation rates were generally consistent between the two sediment trap locations. Mass accumulation rates ranged from 3.69 to 9.59 g/cm<sup>2</sup>-yr, and from 3.55 to 9.16 g/cm<sup>2</sup>-yr at locations HC-ST-100 and HC-ST-101, respectively. Surface sediment dry densities in co-located natural recovery cores were used to convert from mass-based accumulation units (g/cm<sup>2</sup>-yr) to length-based units (cm/yr). The dry density of surface sediments at the sediment trap locations is 0.47 g/cm<sup>3</sup> at HC-NR-100 and 0.42 g/cm<sup>3</sup> at HC-NR-101. Thus, estimated gross sedimentation rates ranged from 7.85 to

20.4 cm/yr, and from 8.45 to 21.8 cm/yr at locations HC-ST-100 and HC-ST-101, respectively.

Gross sedimentation rates varied by almost a factor of three between the fall/winter and summer deployment periods. Higher settling rates in summer may be caused by a more direct influence from Nooksack River runoff, which is carried to the site in clockwise, fair-weather circulation patterns that are more typical of summer months. Settling of suspended sediments from the turbid river plume is apparently enhanced during this time period. During winter months, prevailing counter-clockwise circulation patterns deflect the river plume toward Lummi Peninsula and away from the site, resulting in lower settling rates.

### **Resuspension Rates and Mixed-Layer Thicknesses**

Resuspension rates were estimated by the difference between gross sedimentation rates measured in sediment traps and net sedimentation rates measured in dated cores ( $\text{Resuspension} = [\text{Gross SR} - \text{Net SR}] / \text{Gross SR}$ ) (Baker et al., 1991). Resuspension describes the continuous exchange of sediments between the seabed and water column. The average of the net sedimentation rates estimated using the four different dating techniques was used in the resuspension rate calculations. Resuspension rates ranged from 81 to 93 percent throughout the year, averaging about 90 percent at both locations.

Mixing within the sediment column is a result of bioturbation, tidal wave-induced, or propeller-induced currents. The thickness of the surface mixed layer was interpreted from plots of the natural logarithm of excess Pb-210 activity with depth. The depth at which the Pb-210 activity indicates steady-state decay behavior (constant decrease with depth in the log activity) corresponds to the bottom of the mixed layer; within the mixed layer, Pb-210 activity is theoretically constant. In these cores, however, Pb-210 activity in the mixed layer is erratic, and may be complicated by propeller wash, anchor drag, construction events, and other bottom disturbances. Based on the Pb-210 profiles the base of the mixed-layer was estimated to range between 24 cm (core HC-NR-100) and 11 cm (core HC-NR-102). These values are in general agreement with studies conducted in other Puget Sound embayments (Battelle, 1995).

### **6.2.2 Consistent Recovery in Sediment Profiles**

The patterns of sedimentation observed in the natural recovery cores can also be observed in core sampling data throughout the Whatcom Waterway portion of the Site. As shown in Figure 3-7, the mercury concentrations in surface sediments (0 to 0.3 feet) were consistently lower than in underlying subsurface sediment samples. This consistency of the pattern further confirms the findings of the natural recovery cores and sedimentation estimates.

### **6.2.3 Previous Natural Recovery Modeling**

Bellingham Bay has been the subject of natural recovery studies performed by multiple investigators. Early studies were performed during the 1970s and 1980s, following initial source control efforts by GP (Bothner, 1973; Bothner et al., 1980; and Officer and Lynch, 1989). Those studies concluded that sediment deposition and natural recovery was occurring, as evidenced by declining surface concentrations and observed concentration trends in sediment profiles. This recovery was driven by the significant reduction in source inputs coupled with burial of contaminated sediment with cleaner sediment, mixing of cleaner surface sediments with deeper sediments by burrowing organisms and bottom currents, and exchange of sediments with the overlying water column through resuspension.

As described in the 2000 RI/FS, natural recovery modeling was performed to estimate whether continued sediment concentration reductions would be observed. That modeling projected future reductions in total mercury concentration based on observed changes in sediment concentrations since the 1970s. Those concentrations had decreased following an exponential decay curve. Based on detailed natural recovery modeling, calibrated to site empirical observations, the 2000 RI/FS estimated that over the next 10-year period, surface sediment mercury concentrations would likely decline by an additional 30 to 40 percent in depositional areas.

Actual concentration reductions were confirmed as discussed in Section 5.2. Concentration reductions were observed in 85 percent of the co-located samples retested for sediment mercury concentrations in 2002. Excluding nearshore high-energy areas adjacent to the ASB, average surface mercury concentrations declined by 31 percent (Table 5-1). The observed rates of recovery over this 4 to 6 year period were slightly more rapid than the modeled recovery rates (Table 6-3, originally calculated for a 10-year period). Differences in recovery rates may result from results of source control activities that have been implemented since the 1996 to 1998 time period.

### **6.2.4 Consistency with Natural Recovery Framework**

A weight-of-evidence approach for evaluating natural recovery at contaminated sediment sites has recently been developed by the Remediation Technologies Development Forum (RTDF) Sediment workgroup (Davis et al., 2004), and has been adopted by EPA (2004) in its current draft sediment management guidance. The approach includes steps such as data assessment, modeling, and site monitoring, employing methods and approaches that have been successfully applied at other similar sites. The framework includes five interrelated elements, each of which is described below:

- **Characterize contamination sources and controls:** As described in Section 6.1, sources of contaminants at the Whatcom Waterway Site have been identified and controlled.
- **Characterize fate and transport processes:** Assessment of contaminant fate and transport processes in a natural recovery context requires understanding of environmental processes affecting both sediment and contaminants (Magar et al., 2003). Primary processes of interest include settling/deposition, long-term burial, bioturbation and biological mixing in the bed, pore water diffusion and advection, and chemical partitioning. Key sediment and mercury fate and transport processes were characterized in Bellingham Bay as part of the original RI/FS (Anchor and Hart Crowser, 2000). Following initial monitoring and modeling assessments suggesting the effectiveness of natural recovery at the Whatcom Waterway Site (Bothner et al., 1980; Officer and Lynch, 1989), the RI/FS provided more definitive characterization of the more important processes such as sedimentation, resuspension, and bioturbation. Based on earlier detailed flux measurements performed at the site by Bothner et al. (1980), chemical partitioning, pore water diffusion, and advective processes were not identified as significant mercury fate and transport processes at the site. As described in Section 6.3, most of the outer areas of the Whatcom Waterway site are in stable depositional areas. Exceptions to this general site finding include the nearshore sediments offshore of the ASB that are subject to higher wave energies, and potentially to localized nearshore areas subject to propeller wash in navigation berths.
- **Establish historical record for contaminants in sediments:** Chemical concentration data assembled from past sampling events or from radioisotope-dated cores can be used to establish a historical record for contaminated sediments, and provide important information on the rate and extent of prior natural recovery (Magar et al., 2003). As a result of a variety of academic research studies, regional monitoring programs, and RI/FS investigations, a considerable amount of surface and subsurface sediment chemistry data have been collected over time at the Whatcom Waterway Site. Sediment total mercury sampling data collected with proper quality control procedures are available for the site beginning in the 1970s, and provide a basis to assess historical changes in sediment quality over time. These data corroborate the findings of subsurface sediment sampling profiles and the results of recent surface sediment testing.

- **Corroborate recovery based on biological endpoint trends:** The objective of this evaluation element is to confirm that risk reduction, as indicated by evaluation of chemical conditions, is corroborated using relevant biological measurements. Under SMS, biological endpoints serve as the primary line of evidence for assessing environmental protection. Recovery of sediments has been directly assessed as part of the RI/FS using whole sediment acute and chronic bioassays. These measurements have documented improvement in sediment quality, consistent with the measured declines in contaminant concentrations.
- **Develop acceptable and defensible predictive tools:** The final element in evaluations of natural recovery is to develop defensible predictive tools. Natural recovery modeling and predictions have been corroborated between different modeling packages, including the Officer and Lynch model (1989) used to estimate mercury recovery in sediments of the inner bay, Water Quality Analysis Simulation Program (WASP) models used to estimate recovery of sediments associated with the GP-owned outfall area, and predictive modeling performed as part of the 2000 RI/FS (Anchor and Hart Crowser, 2000). These models have been shown to be effective at predicting the recovery behavior of the system.

The patterns of natural recovery of marine sediments have been well documented at the site. The availability of information for the Whatcom Waterway Site is consistent with all five lines of evidence developed by the RTDF Sediment workgroup (Davis et al., 2004), and adopted by EPA (2004) in its current draft sediment management guidance.

## **6.3 Factors Affecting Sediment Stability**

Natural recovery of chemical and biological conditions within the Whatcom Waterway Site has been well documented, as outlined above. Additional information on factors that could influence future sediment stability was developed for evaluation of the effects of rare, extreme event conditions on contaminant and sediment mobility. Evaluation of future bed stability can be conducted in a number ways, including inference from empirical evaluation of historical data (e.g., core profiles), and prediction based on assessments of extreme event stresses and potential sediment mixing/transport conditions.

Sediments within the Whatcom Waterway Site have already been subjected to a range of bioturbation and hydrodynamic events, including mixing of sediments by benthos, periodic storm surges, and propeller wash. Despite these events the stability of sediments located in deepwater depositional areas is reflected in the core profile data (e.g., Figure 6-1) and the progressive reduction of surface sediment concentrations and toxicity as cleaner sediments have continued to deposit in these areas (Table 5-1). However, sediment

stability in localized areas can differ depending on local conditions. Factors affecting sediment stability are discussed below.

### **6.3.1 Bioturbation**

Bioturbation (sediment mixing) caused by the natural activities of aquatic organisms (e.g., benthos) can affect sediment stability concern in certain situations. At some locations, organisms may be capable of mixing underlying contaminated sediments to the surface, potentially affecting effective long-term isolation of underlying contaminants.

At the Whatcom Waterway Site, the depth of the biologically mixed (bioturbation) zone ranged from 10 to 15 cm (Bothner et al., 1980; Officer and Lynch, 1989; Anchor and Hart Crowser, 2000). In accordance with RI/FS Project Plans and SMS guidance, chemical analyses and confirmatory biological testing at the site has typically focused on samples composited over the top 12 cm of sediment.

Although effective isolation of sediment layers below 12 cm is common and widely reported in Puget Sound, in some situations it may not be an absolute depth of isolation in sediment. For example, some organisms may burrow in sediments deeper than 12 cm. At the particular locations of these burrows or burrowing activities, some mixing or other interaction of surface and deeper layers may occur. Researchers have noted that certain deep burrowing benthos can move material from their relatively deep burrows to the surface, where these reworked sediments accumulate as mounds around the burrow entrance.

Clarke et al. (2001) provide a review of sediment bioturbation issues as they relate to evaluation of long term isolation of contaminants in subsurface sediments. For example, in order to ensure long-term isolation, the overlying clean surface sediments should have a thickness equivalent to the depth where the future bioturbation rate is expected to be inconsequential. A common method of estimating the lower extent of bioturbation is to perform detailed radioisotope dating of sediment cores, as has been performed at the Whatcom Waterway Site (resulting in the 12 cm site-specific SMS point of compliance).

Another method is to examine those organisms present or likely to be present at the site and identify the deepest burrowers. For this reason, ghost shrimp (see below) are often singled out as a particular species of interest. However, it is important to note that identification of the deepest burrowers is a conservative approach to estimating bioturbation in general. That is, using the most extreme observation of burrowing depth available from any instance of any organism in any location may yield an extreme estimate of “bioturbation” for a particular location or situation. There may be little contribution to the overall bioturbation rate from a few deep burrowers if their density is very low. Observations of extreme burrowers thus provide little indication of the actual amount of sediments that might be disturbed by bioturbation, and how



this relates to the overall stratification of sediments. Nevertheless, this approach can provide a starting point as a worst-case estimate of potential depths where bioturbation and mixing may be a future sediment stability concern.

Ghost shrimp (*Neotrypaea californiensis*; formerly *Callinassa californiensis*) are deep burrowing crustaceans whose activities have been suggested to be a particular concern in this context. This species (and other members of the genus) occur throughout Pacific coastal waters of North America, and are commonly noted as one of the deepest burrowers in such benthic environments (Posey, 1986). Their potential colonization and subsequent burrowing/mixing activity is often singled out as a primary uncertainty in regional contaminated sediment stability evaluations. While not numerically abundant within the Whatcom Waterway Site (Broad et al., 1984), ghost shrimp are nevertheless present within the site area.

Reported maximum burrowing depths for adult *N. californiensis* range from less than 40 cm to a maximum of approximately 90 cm (Stivers, 2002). However, typical burrow networks generally extend to less than 40 cm deep at their deepest point. Moreover, ghost shrimp burrow deepest in upper intertidal areas (particularly where the substrate is primarily sand) in order to stay submerged underwater within the burrow for longer periods during low tides. Ghost shrimp prefer intertidal to shallow subtidal locations within estuarine bays, and this is where relatively dense beds (and the deepest burrowing depths) of ghost shrimp can occur. Thus, some of the more extreme observations of ghost shrimp burrowing depths likely reflect a behavioral adaptation to intertidal habitats, which may not be representative of deeper subtidal sediments at the Whatcom Waterway Site.

As discussed in Stivers (2002), the deepest reported burrowing depth for ghost shrimp is approximately 90 cm, and only a small fraction of the shrimp even in a relatively dense intertidal bed reach these depths. The majority of shrimp would be expected to burrow to depths of 60 cm or less. Thus, even in a relatively dense shrimp bed, at depths between 60 and 90 cm, the overall bioturbation rate would be expected to be very low, since only a few individuals would enter this interval. Below 90 cm, the worst-case bioturbation rate is zero for all practical purposes, even in preferred intertidal habitats.

Marine mammals, particularly grey whales, have also been known to disturb shallow subsurface sediments as part of feeding activity. Since termination of commercial whaling in the eastern Pacific, the grey whale population in the eastern Pacific Ocean has recovered to near its historical level of approximately 20,000 individuals, with natural population fluctuations around that level (COSEWIC, 2004). Puget Sound is located adjacent to the migration route of the whales between their summer feeding grounds in the arctic and

their calving ground in Baja, Mexico. Some individuals have been observed to enter Puget Sound and Bellingham Bay and to feed opportunistically. Typically the whales entering Puget Sound stay in the area only a few days, but some individuals have been documented to stay in the area between 50 and 70 days prior to resuming their migration.

Grey whales consume most of their annual diet by pelagic feeding of krill in the Arctic. During peak feeding periods, the whales may consume as much as 1-2 percent of their body weight per day. Grey whales also feed by suction feeding for benthic organisms, typically invertebrates such as shrimp and crab. Suction feeding behavior is generally not observed in intertidal areas, and is confined to subtidal and deep-water areas. The feeding takes place predominantly in the top 20-30 cm of the sediment column, though during some aggressive feeding events, whales can disturb sediments to depths of 90-120 cm. As described in Section 4.4, the concentrations sediment contaminants within the Whatcom Waterway Site are well below the concentrations that could result in potential health impacts to feeding whales. Therefore, the main consideration related to feeding whales within the site area is the potential disturbance of shallow surface and subsurface sediments during aggressive suction feeding that may occur from time to time.

For purposes of evaluating potential sediment disturbances through bioturbation, both sediment penetration by sediment dwelling invertebrates and potential periodic disturbances by feeding whales can result in disturbance of the upper 30-40 cm, and as deep as 90-120 cm of the sediment column in subtidal areas. These depths are similar to the depths potentially disturbed by anchor drag and navigation disturbances. These potential disturbance depths are useful in the analysis of sediment contaminant distribution and in the design and analysis of long-term effectiveness for potential remedial actions. Sediment contaminant distribution for these sediment depths was discussed in Section 5.3 of this RI report. The remedial alternatives evaluation in the Feasibility Study addresses long-term effectiveness considerations including sediment stability.

### **6.3.2 Wind and Wave Activity**

The bioturbation discussion presented above provides an assessment of potential extreme sediment mixing events resulting from worst-case bioturbation forces, and possible implications of such a condition on sediment stability evaluations at the Whatcom Waterway Site. Possible additional hydrodynamic forces such as periodic storm surges, propeller wash, and anchor drag were also evaluated in this sediment stability evaluation, consistent with the evaluation framework presented in Palermo et al. (1998a and 1998b) and Erickson et al. (2003).

Sediments within the Whatcom Waterway Site have already been subjected to a range of hydrodynamic events. In general, the stability of these sediments as

reflected in the core profile and natural recovery data discussed above suggests that sediment at the site has been stable over time under the range of dynamic processes that have occurred in the system over the past 30 years.

Wind and wave activity vary with water depth and location throughout the Whatcom Waterway Site. In relatively shallow water depths (e.g., less than 10-15 feet) wind-driven storm waves can produce increases in bottom velocities that can resuspend settled sediments. These forces are proportional to the sizes of the waves, which are in turn influenced by the wind direction, fetch, and duration and the localized geography and bathymetry. At the Whatcom Waterway Site, the greatest wind and wave exposures are experienced by the shorelines offshore of the ASB and of the Bellingham Shipping Terminal, because these areas are exposed to the prevailing offshore winds, and because these areas are exposed to wind-waves with the longest fetch in which to build. The predicted bottom velocities associated with a particular wave height and period generally increase as the water depth decreases. Intertidal sediments are exposed to breaking waves and are most subject to wave erosion, depending on the shoreline geometry and composition. Lower but significant levels of wave action occur along the sides of the Whatcom and I&J Waterway and in portions of the Log Pond. Vessel wakes can also generate waves of varying sizes depending on the type and speed of vessel movement and the location of the vessel relative to shoreline areas.

The effects of wind and wave activity can be observed to some degree in the particle size distribution in sediments throughout the site. In most deepwater areas, the sediments are composed of fine-grained sediments that have deposited over time. These areas are below the depths at which wind and wave effects are significant. In the shallow-water areas offshore of the ASB and in certain other shallow-water areas along the waterways, the particle size has a lower composition of fine-grained sediments, in part due to the resuspension of finer-grained materials by wind and wave effects. These patterns are also influenced by anthropogenic disturbances such as the placement or erosion of coarse grained materials in certain areas.

The potential for wind and wave disturbances is relevant to the evaluation of the long-term stability of impacted sediments in the absence of remedial actions, and also for the design of remedial actions involving capping or shoreline changes. These issues are discussed directly as part of the Feasibility Study and the evaluation of remedial alternatives for the Whatcom Waterway Site. Remedial design activities for the final cleanup action will also include additional evaluations of the impacts of wind and wave disturbances on sediment stability, including potential influences of vessel-induced wakes.

### **6.3.3 Propeller Wash and Anchor Drag**

Propeller wash from vessels can produce increased bottom velocities and in some cases localized sediment resuspension. The propeller wash effects are generally proportionate to the size, draft, and power of vessels, with larger, deeper and more powerful vessels exhibiting propeller wash effects to greater depths. However, propeller wash effects are influenced by propeller type, orientation, water depth, and duration.

While some propeller wash effects can occur transiently in offshore areas, the effects are most significant in waterway and berth areas where navigation activity is concentrated, and where water depths are typically shallower and matched to the size of the vessels using the channels and berths. In extremely shallow-water intertidal or shallow subtidal areas, vessel access is limited or precluded. In these areas, propeller wash effects would typically be observed only as a result of indirect activities (e.g., vessel maneuvering in an adjacent deepwater area, with resultant propeller wash directed toward the shallow-water area). This type of effect was evaluated as part of the design of the Engineering Design Report for the Log Pond Interim Action (Anchor, 2001a).

As the water depth increases, an increased variety of vessel types, depths, and power can utilize a navigation area, increasing the range of potential propeller wash conditions that may be experienced. In deepwater areas, the propeller wash effects become insignificant due to the attenuation of propeller wash velocities with depth below the vessel. The specific significance thresholds vary with the types of vessels that may be present in the area, the water depth, and the sediment particle size.

The deepwater portions of the Whatcom Waterway navigation channel allow vessels with drafts up to about 30 feet. This depth is considered intermediate by current navigation standards. True deepwater vessels (e.g., post-Panamax container vessels, the largest cruise ships, or oil tankers) are incapable of entering the waterway or using the berth areas, or even entering many portions of Inner Bellingham Bay due to natural water depth limitations. The main propeller wash conditions relevant to the deepwater portions of the Whatcom Waterway are bow thruster activity on larger vessels with intermediate (i.e., 20-30 ft) drafts, or the propeller wash from tugs used in assisting the berthing of the larger vessels.

For the Inner Waterway with water depths of approximately 18 feet below MLLW, vessel traffic can include small tugs and barges, recreational vessels, sailboats, whale watching boats, passenger-only ferries, and other vessels ranging in draft from less than 5 feet to 18 feet. Based on the Log Pond design analysis, as well as other regional evaluations of propeller wash, the propeller wash created by these types of vessels would not be significant at water depths greater than around 30 feet below MLLW (Ecology, 1995; PIE, 1998;

WSF, 1999), but may be significant in shallow-water areas where depths are closer to the draft of the vessels (Anchor, 2000b).

When the bottom velocities created by propeller wash conditions exceed the stability threshold of the sediments present in the effected area, the surface sediments of the bed may begin to erode. The depth to which the erosion will occur varies with the velocity, the sediment type, the duration and the repetition of the event. Detailed propeller wash scour modeling and tracking performed at other similar sites in Puget Sound (Ecology, 1995; PIE, 1998; WSF, 1999), shows that the maximum depth of potential propeller wash scour can vary from shallow effects (i.e., less than 10 cm) to worst-case scour depths of approximately 90 cm. The greatest scour depths are observed when all factors are aligned, resulting in high bottom velocities in the same location and orientation and occurring repeatedly (e.g., repeated moderate to high power, localized propeller wash occurring at ferry terminals). Scour depths are generally much lower where propeller wash events are transient and in inconsistent orientations (e.g., in offshore areas where vessel traffic patterns are variable).

Anchor drag is the effect caused when vessel anchors become buried in surface and shallow-subsurface sediments. The burial and retrieval of the anchor can cause mixing of the sediments in the localized area around the anchor. Anchor drag is most significant in designated anchorage areas. In navigation areas where vessels are secured by “tying up” to docks, wharves, or floats, anchor drag is generally not significant. Anchor drag is also not generally significant when the use of anchors is reduced through the use of permanent moorage floats.

The depth at which anchor drag can cause mixing of sediments varies with the type and size of vessel, the size and type of anchor, and the bottom conditions in the anchorage area. For small vessels, the depth of anchor drag effects is commonly in the range of 10-30 cm in soft sediments. For larger vessels, the range of depths of localized mixing can be 10 to 90 cm (Palermo et al., 1998a and 1998b). This depth is similar to the range of potential disturbances associated with propeller wash and bioturbation.

#### **6.3.4 Seismic Influences on Sediment Stability**

The Whatcom Waterway site is located within the Puget Sound Basin, an area of active seismicity. The Site could be affected by earthquakes from three primary sources: shallow crustal faults, deep intraslab earthquakes, and interpolate (subduction) earthquakes. The contribution of each of these sources to ground shaking hazards has been evaluated by the U.S. Geological Survey (USGS; <http://geohazards.cr.usgs.gov>).

USGS disaggregation analyses indicate that the hazard in Bellingham is controlled predominantly by shallow crustal earthquakes at distances of less

than 25 kM at a return period of 2,475 years. The relative contribution of crustal sources is expected to be even larger at the 475 year return period level.

Liquefaction can be observed in loose, saturated, cohesionless soils subjected to strong earthquake shaking. Cohesive soils, such as plastic silts and clays, are not susceptible to liquefaction, though sensitive clays may exhibit similar behavior. The potential for liquefaction to occur therefore varies from location to location with area lithology, and can affect certain site sediments, and upland soils adjacent to certain site sediment areas.

The primary effects of liquefaction are flow sliding or lateral spreading. Flow sliding occurs when the residual shear strength of a liquefied soil is lower than the shear stresses required to maintain static equilibrium. While it occurs relatively rarely, flow sliding can lead to large lateral soil movements, either during or following earthquake shaking. Lateral spreading can also produce horizontal soil movements during strong ground motion. The displacements produced by lateral spreading typically develop during earthquake shaking and are complete by the time earthquake shaking has ended.

Seismic stability analyses are typically incorporated into the design and permitting for implementation of cleanup actions, and for other types of construction. For example, the Engineering Design Report for the Log Pond Interim Remedial Action (Anchor, 2000) assessed quantitatively the potential for flow sliding and lateral spreading at the Log Pond cap area. Such analyses will be performed as part of the design of any remedial action at the Whatcom Waterway site.

Based on site lithology, and the generalized seismic information for the site, seismic issues are unlikely to significantly affect sediment conditions within most of the deepwater site areas. These areas are relatively flat, and lateral spreading and flow sliding are unlikely to occur. The potential for significant sediment movement increases for steep shoreline areas and bulkheaded waterfront areas, due to the lower stability of these steeper slopes. Engineering analyses during remedial design for site cleanup will address measures to mitigate potential seismic stability concerns in these areas.

**Table 6-1 Summary of Estimated Sedimentation Rates from 2000 RI/FS**

| Natural Recovery<br>Core Number    | Sedimentation Rate in cm/yr |                           |                          |                              |                                  |
|------------------------------------|-----------------------------|---------------------------|--------------------------|------------------------------|----------------------------------|
|                                    | Pb-210<br>Decay             | Onset of Cs-137<br>(1950) | Peak of Cs-137<br>(1967) | Peak of<br>Mercury<br>(1970) | Average<br>Sedimentation<br>Rate |
| HC-NR-100                          | 1.4                         | 1.69                      | 1.43                     | 1.54                         | 1.52                             |
| HC-NR-101                          | 1.06                        | 1.99                      | 1.41                     | 1.61                         | 1.52                             |
| HC-NR-102                          | 2.07                        | 1.52                      | 1.52                     | 1.98                         | 1.77                             |
| Overall Average Sedimentation Rate |                             |                           |                          |                              | 1.6                              |

**Note:**

Table from 2000 RI/FS Report (Table 9-1)

**Table 6-2 Summary of Average Net Sedimentation, Gross Sedimentation, and Resuspension Rates from 2000 RI/FS**

| <b>Natural Recovery<br/>Core Number</b> | <b>Average Estimated Net<br/>Sedimentation Rate in<br/>cm/yr</b> | <b>Estimated Gross<br/>Sedimentation Rate in<br/>cm/yr</b> | <b>Calculated<br/>Resuspension Rate in<br/>Percent</b> |
|---|--|--|--|
| HC-NR-100,<br>HC-ST-100                 | 1.52   | 7.85   | 81   |
| HC-NR-101,<br>HC-ST-101                 | 1.52   | 8.45   | 82   |

**Note:**

Table from 2000 RI/FS Report (Table 9-1)

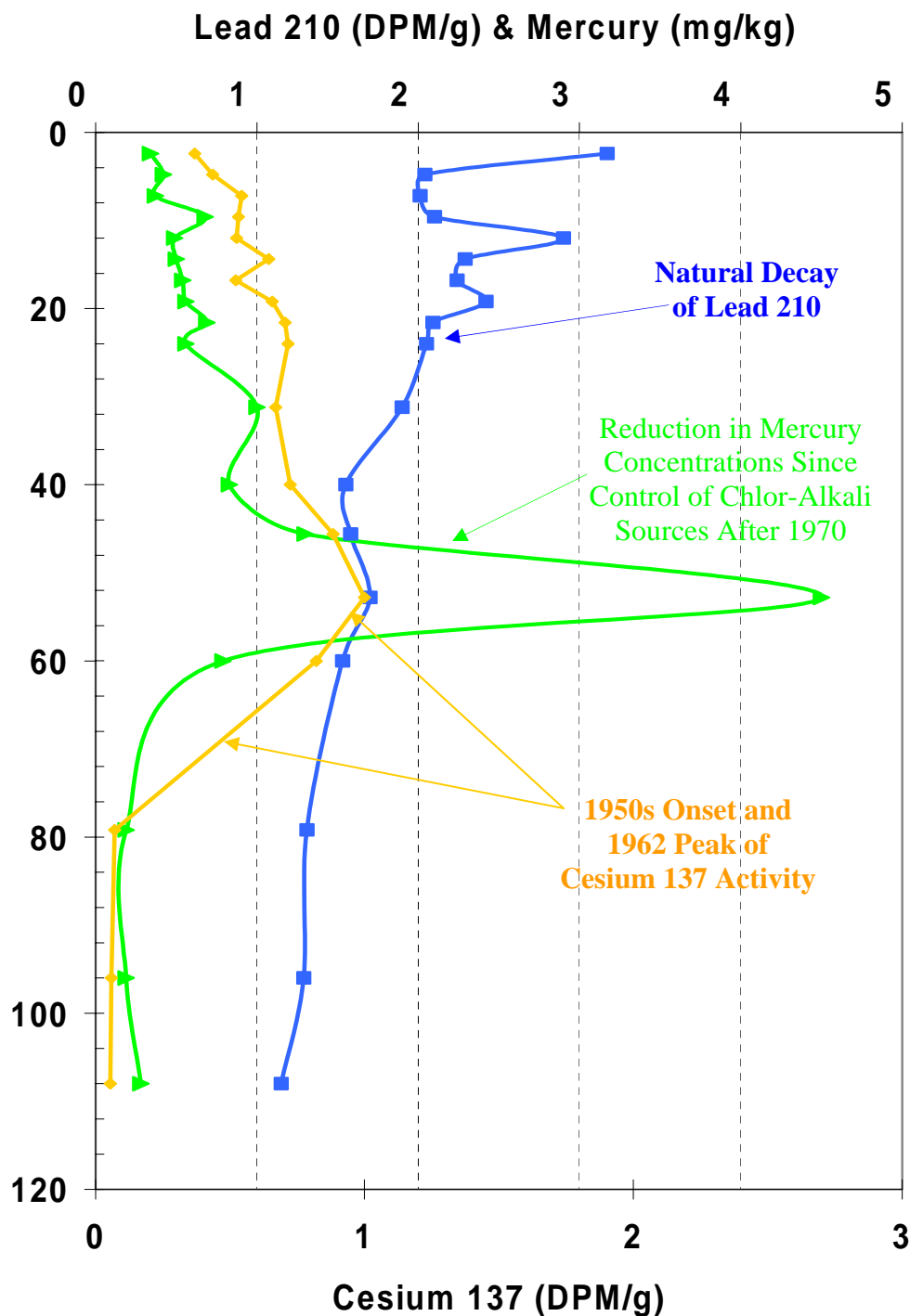


**Table 6-3 Ten-Year Recovery Projections of Mercury Concentrations from 2000 RI/FS**

|                              |  |                                      |                     |                |   | Sediment Mercury Concentration in mg/kg |                                |
|------------------------------|--|--------------------------------------|---------------------|----------------|---|---|--------------------------------|
| Natural Recovery Core Number | Maximum Sample Interval Used in Regression (in cm) | Number of Samples Used in Regression | Regression R2 Value | Standard Error | Average Net Sedimentation Rate (in cm/yr) | Year 1995                               | Year 2005 (+/- Standard Error) |
| HC-NR-100                    | -44.2  | 11                                   | 0.59                | 0.05944        | 1.52                                      | 1.3                                     | 0.80 (+/- 0.12)                |
| HC-NR-101                    | -41.6  | 12                                   | 0.68                | 0.0751         | 1.52                                      | 1.7                                     | 1.12 (+/- 0.15)                |
| HC-NR-102                    | -45.6  | 13                                   | 0.81                | 0.05679        | 1.77                                      | 0.34                                    | 0.23 (+/- 0.11)                |

**Note:**

Table from 2000 RI/FS Report (Table 9-1)



**Notes:**

Core data from sample station HC-NR-102.

Left axis data represents the depth beneath the mudline, in centimeters.

DPM: Disintegrations per minute – a measure of isotopic activity.

Refer to Appendix B for raw data summaries and data from other natural recovery cores.



PORT OF BELLINGHAM  
WHATCOM WATERWAY

EXAMPLE CORE PROFILE  
FROM NATURAL RECOVERY  
EVALUATION

Date: 08/2006

File: 8876/RIFS

FIGURE 6-1

## 7 Results of Engineering Testing

In addition to the information contained in previous sections of this report, a number of engineering studies and other sediment evaluations were conducted to support development of a Feasibility Study, and to inform future remedial design activities. The following sections provide a summary of these engineering evaluations.

- Bench-Scale Engineering Studies (Section 7.1)
- Sediment Management Evaluations (Section 7.2)
- *In Situ* Sediment Treatment Testing (Section 7.3)
- Dewatering Tests for ASB Sludges (Section 7.4).

### 7.1 Bench-Scale Engineering Studies

In spring/summer 2002, a number of bench-scale studies were performed in support of the RI/FS evaluation of potential confined disposal remediation alternatives. The results of these studies were summarized in the Pre-Remedial Design Evaluation report (Appendix A). An overview of the bench-scale and engineering studies is provided below.

- **Geotechnical Testing of Waterway Sediment Composite:** A composite sample of sediments was tested for geotechnical properties. The purpose of the testing was to evaluate geotechnical properties of the materials that could affect the design and construction of a confined disposal facility. The tests performed on the sediment composite included consolidation tests, water content, grain size distribution, Atterberg limits, specific gravity, hydraulic conductivity, and effective porosity. The results are useful in defining the settlement and consolidation behavior of materials placed in a containment cell or fill, defining the dewatering behavior of the materials, and in defining the final bearing strength of the cap placed over the top of the containment cell.
- **Waterway Sediment Elutriate Testing and Settling Tests:** In addition to leaching tests performed as part of the 2000 RI/FS, two types of elutriate testing were performed as part of the PRDE study (Appendix A) for evaluation of potential water quality impacts during dredging. The testing included both the dredge elutriate test (DRET) method, and the Modified elutriate test (MET) method. Column settling tests were also performed on the composite. The column settling test (CST)\_provides information on the settling behavior of suspended solids that can be generated during dredging either at the point of dredging, or at the point of disposal. Results of the DRET, MET, and CST bench-scale evaluations are described in Appendix A.

- **Multi-Site Pancake column leach testing (PCLT):** To support the feasibility study evaluation of on-site multi-user confined disposal alternatives, testing was performed using the PCLT protocol. The PCLT test evaluates chemical mobility associated with sediment porewater/leachate following placement of impacted materials in a confined disposal facility. The PCLT was conducted over the period from June to December 2002, during which a total of 27 leachate samples, constituting approximately 22 pore volumes, were collected from the column and analyzed for chemical properties. Peak leachate concentrations were observed in the PCLT concurrent with “salt wash-out” conditions, as described in Myers et al. (1996). Peak mercury concentrations in the PCLT leachate rose from initial low concentrations (less than 0.025 µg/L) to salt wash-out concentrations ranging from 0.800 µg/L to 1.29 µg/L. Washout increases were also observed for tributyl tin which was present in the test composite mainly due to sediments contributed from the Weldcraft and Marine Services Northwest sites. These sediments had been evaluated along with the Whatcom Waterway Site materials to assess the feasibility of joint management of impacted sediments as part of a multi-user disposal site operation. Results indicated that changes in sediment redox conditions and salinity conditions could enhance mercury and tributyl tin mobility, and that confined disposal site design would need to include evaluation of measures to ensure protection of groundwater and surface water quality adjacent to the containment site. Such measures would likely include confinement of the materials within the saturated zone to minimize redox condition changes, and evaluation of leachate/groundwater/surface water interactions, and the measures that can be taken to minimize contaminant flux from the confined disposal facility.

## **7.2 Sediment Management Evaluations**

The potential suitability of sediments from the Outer Whatcom Waterway and from the I&J Waterway for PSDDA disposal or beneficial reuse was evaluated as part of previous RI/FS testing and parallel PSDDA evaluations (Appendix H). Two rounds of testing have indicated that the Outer Waterway and I&J Waterway sediments are likely suitable for management consistent with PSDDA program requirements. Final suitability determinations are subject to additional testing to comply with full PSDDA program requirements and data recency requirements.

In contrast to the sediments of the offshore portion of the Outer Waterway and the I&J Waterway, PSDDA evaluations performed previously on sediments at the Bellingham Shipping terminal (Striplin, 1997) and in portions of the Inner Waterway have demonstrated exceedances of criteria for beneficial use or

PSDDA disposal (Appendix H). Sediments dredged from these areas would be subject to use restrictions, likely requiring application of confined disposal or upland disposal methods. Leachability testing using the Toxicity Characteristic Leaching Potential (TCLP) test protocol was performed as part of the 1997 PSDDA evaluations. That testing demonstrated that Whatcom Waterway Site sediments would not exceed state or federal TCLP mercury limits for Subtitle D landfill disposal. Sediment management options are discussed in detail as part of the Feasibility Study.

## 7.3 ECRT Pilot Testing

Electro-chemical reductive technology (ECRT) was originally developed in Europe. The technology is based on imposing a direct electrical current with a superimposed alternating energy current via *in situ* electrodes, to optimize and utilize the electrical capacitance properties of soil and sediment particles.

Under optimum conditions, the technology purports the ability of oxidizing organic chemicals *in situ*, and concurrently enhancing the mobility of metals such as mercury, resulting in metal precipitation onto the electrodes. To date, the technology has been applied at one sediment site in Europe containing elevated concentrations of mercury and other metals. However, the technology has not yet been applied on a full scale in the U.S. for sediments.

A pilot test of ECRT was performed at the Log Pond area of the Whatcom Waterway Site. The test was funded by EPA's National Risk Management Research Laboratory and the Superfund Innovative Technology Evaluation program and Ecology. The pilot test was performed between August of 2002 and March of 2003, and involved the installation of a set of test electrodes (nine cathodes and nine anodes) within a 50-foot by 50-foot pilot test plot in the western corner of the Log Pond, near the Bellingham Shipping Terminal. The treatment cost for this 460 cubic yard test plot was approximately \$388,000 or approximately \$838 per cubic yard treated. Concentrations of subsurface sediment constituents were measured before, during, and after conclusion of the pilot test treatment period.

Results of testing demonstrated that there was no significant change in mercury concentrations in the test plot sediments over time. The ECRT process was determined to be ineffective at achieving reductions in mercury concentrations, which was the primary purpose of the technology. There were also no significant changes in the test plot sediment concentrations for phenolic compounds. Therefore, the secondary objectives of the test plot (to achieve concentration reductions for organic contaminants) were not achieved.

One factor that was cited by the technology vendor as being responsible for the poor performance of the technology was the corrosion of electrical connections to the treatment electrodes, even though the vendor took

measures to isolate the connections from the marine environment. A final testing report is to be published by EPA as part of its Innovative Technology Evaluation Report series. The results of the ECRT test plot demonstrated that the technology is not ready for full-scale application at marine sediment sites, because it has not been demonstrated capable of achieving significant reductions in target contaminants. The treatment Pilot also demonstrated that the costs of the treatment may be very high, even if improvements to its performance can be achieved in the future.

## 7.4 Sludge Dewatering Tests

In support of the Feasibility Study evaluations of sediment removal, treatment and disposal options, dewatering tests were performed during 2004 for the ASB sludges. These tests were performed under Addendum No. 5 to the Project Work Plans. The testing report is included as Appendix D.

The dewatering tests were performed on the ASB sludges to evaluate the operational parameters for mechanically-enhanced dewatering technologies that could be used to separate ASB sludges from entrained waters. These technologies are not typically practical for application to aquatic sediments. But the ASB sludges have very high water content, increasing the practicability of these technologies for achieving mass and volume reduction. As noted in Table 5-3, the average solids content of the ASB sludges is 17 percent, over three times lower than the average solids content of the Whatcom Waterway materials. The practicability of sludge dewatering by solids separation was established both by these high initial water contents, as well as by the successful application of the technology during localized sludge removal performed previously as part of ASB maintenance activities.

The dewatering tests involved three steps. First, composite sludge samples were collected from the ASB. Second these samples were tested to identify dewatering additives that may enhance mechanical separation of the sludges. Finally, bench-scale separation testing was performed to identify the range of final solids content achievable through commercially-available centrifugation or hydrocyclone separation technologies. These technologies are commercially available and are used in the separation of wastewater treatment solids at wastewater treatment plants and industrial facilities around the country. The technologies are relatively costly, but can achieve a significant reduction in sludge mass and volume. The practical limits of the technology vary with the properties of the specific sludge materials. Generally wastewater treatment solids have a high water retention behavior, resulting in practical solids content limitations in the 30-50 percent range. As described in Appendix D, the dewatering tests indicated that the average solids content of the ASB sludges could be increased by a factor of two over its *in situ* solids content through enhanced dewatering.

## 8 Conceptual Site Model

This section summarizes the results of the Remedial Investigation, and provides a Conceptual Site Model (CSM) for the Whatcom Waterway Site. The CSM provides a concise summary of the information developed in the RI process. The key elements of the CSM include the following:

- Contaminants and Sources (Section 8.1)
- Nature and Extent of Impacts (Section 8.2)
- Contaminant Fate and Transport Processes (Section 8.3)
- Exposure Pathways and Receptors (Section 8.4)

Graphical illustrations of the CSM are included in Figures 8-1 and 8-2. The CSM is provided to assist the reader in review of site information, and to assist the reader in evaluating the appropriateness of potential remedial strategies discussed in the site FS (Volume 2 of the RI/FS). The reader should refer to previous sections of this report for the detailed information on which the CSM is based.

### 8.1 Contaminants and Sources

As measured by relative concentration and frequency of detection, the principal contaminants in the site sediments are mercury, 4-methylphenol, and phenol. Table 8-1 summarizes the principal contaminants and sources for the Whatcom Waterway Site. The table includes a summary of the status of source control activities. Refer to Section 6.1 of this report for a more detailed discussion of the site source control status.

- **Mercury Contamination is Predominantly from Historical Sources:**  
The primary source of mercury within the Whatcom Waterway Site sediments was the discharge of mercury-containing wastewaters from the Chlor-Alkali Plant between 1965 and the 1970s. This historic source of mercury contamination has been controlled. Following initial pollution control upgrades by Georgia Pacific in the early 1970s, direct discharge of Chlor-Alkali Plant wastewaters to the Whatcom Waterway was terminated. Then in 1999 the Chlor-Alkali Plant was closed by Georgia Pacific, eliminating the generation of mercury-containing wastewater. The clean up of the Log Pond area in 2000 and 2001 controlled the secondary source of mercury by capping contaminated sediments in this area. Some regional and natural sources of mercury continue to exist, but these sources are not expected to result in exceedances of Site screening levels.
- **Phenolic Compounds are Predominantly from Historical Sources:**  
The primary sources of phenolic compounds within the Whatcom

Waterway Site sediments include historical wood products handling and log rafting, historical pulp mill discharges prior to implementation of primary and secondary wastewater treatment, and potential lesser contributions from historical stormwater and wastewater discharges. These sources have been controlled. Wood products handling activities are less common than there were historically, and additional regulatory and permitting requirements minimize the potential for discharges of wood wastes to sediments. Pulp mill wastewater discharges were better controlled after the 1960s and 1970s, and discharge of process wastewaters to the Whatcom Waterway were terminated in 1979. The pulp mill was closed by GP in 2000, terminating the discharge of pulp and chemical plant wastewaters to the ASB.

Because primary contamination sources have been controlled, the main focus of the remaining site cleanup actions will be to address secondary contamination sources, the residual contamination in sediments at the site.

A number of other contaminated sites are located in the vicinity of the Whatcom Waterway Site and are being addressed by Ecology. These sites do not represent a current source control concern for Whatcom Waterway Site sediments or surface water quality.

## **8.2 Nature and Extent of Contamination**

The nature and extent of contamination impacts within the Whatcom Waterway Site have been conclusively determined through over a decade of intensive investigations as part of the RI/FS and Bellingham Bay Pilot activities. These investigations in turn build on previous studies performed by academic researchers, regulatory agencies, local industry, and government. The result is a wealth of knowledge about site conditions, and the factors that influence the selection of a final site cleanup.

The findings of the site investigations are the focus of this RI report. Table 8-2 provides a quick summary of the principal RI activities and their findings. These findings are graphically displayed as a CSM in Figures 8-1 and 8-2.

- **Waterway Sediments:** The Whatcom Waterway sediments generally consist of a layer of soft, silty, impacted sediments. The elevation and thickness of the impacted layer varies with location, but is generally between 2 and 10 feet in thickness. The sediments are thickest in historically dredged and filled areas along the Inner Waterway. The impacted Waterway sediments are subject to natural recovery by ongoing deposition of clean sediments. Except in some high-energy, nearshore areas offshore of the ASB, the impacted sediments are covered by a layer of clean sediments. These clean sediments have been naturally deposited, and the



surface sediments of the bioactive zone comply with sediment screening levels protective of environmental receptors. This process of natural recovery is expected to continue. Mercury concentrations within the site subsurface sediments are typically in the low part-per-million range, and average subsurface mercury concentrations decrease with distance from the Log Pond source area. Phenolic compounds are also present in the Waterway in the low part-per-million range. The highest phenolic concentrations were detected in subsurface sediments within the Inner Waterway, near the historic pulp mill effluent discharge locations from the 1950s and 1960s. The impacted sediments are underlain by clean, native sandy sediments of varying thicknesses.

- **Log Pond Sediments:** The Log Pond area was the site of the historic mercury-containing wastewater discharge from the Chlor-Alkali Plant during the 1960s and 1970s. Subsurface sediments in this area contain the highest mercury levels present at the site. This area was remediated by capping as part of an Interim Action that was implemented in 2000 and 2001. Sediment monitoring since that time has demonstrated that the cap is performing well, and is successfully preventing underlying contaminants from migrating upward through the cap. Monitoring of groundwater discharges in the cap area has demonstrated no ongoing impacts to surface water quality or cap conditions from the adjacent Chlor-Alkali Plant upland areas. Biological monitoring has demonstrated that the capped area has recovered biological functions for benthic and epibenthic organisms, for juvenile salmonids, and shellfish. Tissue monitoring has demonstrated that bioaccumulation risks have been successfully controlled, and crab tissue sampled from the area is not significantly different from crabs collected from clean reference sites. Some wave-induced erosion has been noted at the shoreline edges of the cap, and enhancements to these areas will be required to prevent cap recontamination and to maintain the long-term protectiveness of the remedy. The Feasibility Study includes proposed cap enhancements as part of the final remedial alternatives for the Whatcom Waterway Site.
- **ASB Areas:** Figure 8-2 provides a graphical summary of the conditions in the ASB area. The ASB was originally constructed as a stone, sand, and clay berm, enclosing a basin dredged in 1978. Some impacted sediments exist underneath portions of the berm. However, the berm consists primarily of clean materials imported at the time of construction. A thick layer of wastewater treatment sludges has accumulated within the ASB. These sludges are soft, flocculent, high-organic materials containing elevated levels of mercury, phenolic compounds and other contaminants. However,

the sludges have not significantly impacted the clean native sands underlying the basin. The evaluation of potential remedial alternatives for the ASB area will take into account the special physical and chemical properties of the ASB materials, and the planned future uses of the ASB area.

- **Starr Rock Area:** Site investigations have documented the nature and extent of contamination present at the former Starr Rock dredge disposal site. This area is located in a deep-water, low energy portion of the Whatcom Waterway Site. Natural recovery has occurred in this area, with impacted mercury and phenol-impacted sediments being covered by clean sediments. There are no current exceedances of site screening levels in this area.

## **8.3 Fate and Transport Processes**

Sediments within the Whatcom Waterway Site are acted upon by natural and anthropogenic forces that affect the fate and transport of sediment contaminants. Fate and transport processes are summarized on Table 8-3. Significant fate and transport processes evaluated as part of the RI include the following:

- **Sediment Natural Recovery:** Processes of natural recovery have been extensively documented within the Whatcom Waterway Site. Most areas of the site are stable and depositional, and clean sediments continually deposit on top of the sediment surface. RI investigations have documented depositional rates and have verified that patterns of deposition and natural recovery are consistent throughout most site areas. The exception to this general observation is in nearshore, high-energy areas where recovery rates are reduced by the resuspension of fine-grained sediments. In all other areas of the site, cleaner sediments are consistently observed on top of impacted sediments throughout most areas of the site. As part of the 2000 RI/FS, site data and recovery models were used to produce quantitative estimates estimate natural recovery rates. These estimates were then empirically verified by re-sampling surface sediments and comparing observed recover rates with model predictions.
- **Erosional Processes:** The effects of wind/wave erosional forces represent the principal natural process affecting sediment stability. RI investigations and FS engineering evaluations have identified high-energy, nearshore areas where the natural deposition of fine-grained sediments does not occur, or occurs at slower rates. In these areas, fine-grained sediments can be resuspended, mixed, or transported by wave energy. The erosional forces vary with

location, water depth, sediment particle size, and shoreline geometry. These forces are minimal in deep-water areas which represent the majority of the Whatcom Waterway Site. The Feasibility Study incorporates analyses of erosional forces in consideration of site remediation areas and applicable technologies.

- **Navigation Dredging and Shoreline Infrastructure:** Navigation dredging and the construction of associated shoreline infrastructure has been a prominent feature of the Whatcom Waterway Site, and has shaped the current site lithology. The RI/FS includes extensive discussion of historic and future navigation and infrastructure issues that could affect site sediments. The FS incorporates potential future dredging activities as part of the evaluation of the long-term effectiveness of the remedial alternatives. The companion EIS document assesses the inter-relationships between site cleanup decisions and community land use and habitat enhancement objectives, consistent with the goals of the Bellingham Bay Demonstration Pilot.
- **Other Processes:** As part of the evaluation of sediment stability, the RI included a discussion of bioturbation, propeller wash, and anchor drag. These processes can result in periodic disturbances of the sediment column, and can enhance mixing of surface sediments with underlying sediments. These processes are all ongoing and are incorporated in the empirically measured rates and performance of natural recovery. However, they are relevant in the evaluation of the long-term stability of subsurface sediments. Propeller-wash in particular will affect sediment stability in near-shore navigation areas. These factors are incorporated into the FS analysis of remedial alternatives.

## **8.4 Exposure Pathways and Receptors**

Section 4 of this RI report discusses the principal environmental receptors and exposure pathways applicable to the Whatcom Waterway Site. That section also discusses the site screening levels that are used to evaluate protection of these receptors. Exposure pathways and receptors are illustrated in Figures 8-1 and 8-2, and are summarized in Table 8-4.

- **Protection of Benthic Organisms:** The primary environmental receptors applicable to the Whatcom Waterway Site consist of sediment-dwelling organisms. These benthic and epibenthic invertebrates are located near the base of the food chain and are important indicators of overall environmental health. Both chemical and biological monitoring are used to test for toxic

effects. Chemical and biological standards specified under the Sediment Management Standards are used to screen for such effects. The whole-sediment bioassays provide an ability to test for potential synergistic effects between multiple chemicals, and to test for potential impacts associated with parameters not measured as part of chemical testing.

- **Protection of Human Health:** Mercury is one of the primary contaminants present at the Whatcom Waterway Site. Mercury can be converted to methylmercury which in turn can bioaccumulate through the food chain. As part of the 2000 RI/FS a BSL was developed that would be protective of both recreational and tribal fishing and seafood consumption practices. The BSL was developed using very conservative exposure assumptions, to ensure that the value would be protective. An additional degree of protectiveness has been obtained in the way that the BSL is applied by Ecology to the site decision-making. Specifically the BSL has been applied as a “ceiling” value for all surface sediments at the site, including individual data points or clusters. This application provides a substantial additional degree of protectiveness, because it is the area-weighted average sediment mercury concentration that drives biological risks. Area-weighted average concentrations within the Whatcom Waterway Site are between two and three times lower than the BSL itself. The FS considers remediation of all areas exceeding the BSL on a point-by-point basis, even though the area-weighted average is already below the BSL. This application of the BSL further reduces the potential risks associated with the site.
- **Protection of Ecological Health:** As with human health, ecological receptors can be impacted by mercury bioaccumulation. However, the application of the BSL to cleanup at the site ensures protectiveness to ecological receptors. The protectiveness of the BSL to ecological receptors was evaluated in two ways. First, the protectiveness of the BSL was evaluated against potential marine mammal exposures. Second, bioaccumulation testing has been performed on sediments from the Whatcom Waterway Site at concentrations exceeding the BSL, demonstrating no significant bioaccumulation at these sediment concentrations. Third, tissue monitoring has been performed at the site as part of the Log Pond Interim Action. That monitoring has shown that compliance with the BSL prevents the accumulation of mercury in crab tissue in comparison to clean reference areas. Based on these three lines of evidence, the compliance with the mercury BSL and with SMS criteria for benthic organisms results in protection of ecological receptors.

- **Other Considerations:** The Feasibility Study includes evaluations of remedial technologies that may trigger new exposure pathway and receptor risks. For example, dredging of impacted sediments triggers short-term risks at the point of dredging and in material handling areas, and during transport of these materials to the disposal site. Additional exposure pathways and receptors are potentially affected at the location of dredge material disposal. The RI included engineering testing that was focused on providing empirical data necessary to evaluate these additional exposure pathways and receptor risks. These data are then used as part of the FS, in conjunction with applicable regulatory guidelines and requirements, to evaluate the feasibility, protectiveness, and costs of different remedial strategies.

## **8.5 RI Conclusions**

In summary, the nature and extent of contamination at the Whatcom Waterway Site has been defined. Primary contaminant sources have been controlled, and sufficient information is available to define protective cleanup levels for final site cleanup. The final site cleanup will address areas of remaining sediment contamination, and will protect human health and environmental receptors by terminating remaining exposure pathways. The data collected in the RI are sufficient for development of the site FS. The CSM provides a summary of significant factors that must be addressed by the remedial alternatives evaluated in the FS.

**Table 8-1 Summary of Principal Contaminants and Sources**

| Principal Site Contaminants | Principal Source(s)                              | Source Control Status   |
|-----------------------------|--|---|
| <b>Mercury</b>              | <b>Wastewater Discharges to Log</b>              | <b>Controlled</b><br>- Discharges terminated in the 1970s   |
|                             | <b>Groundwater Discharges to Log Pond</b>        | <b>Controlled</b><br>- Monitoring indicates no continuing discharges affecting Log Pond sediments or water quality<br>- Additional actions to be evaluated as part of the chlor-alkali site RI/FS and site cleanup  |
|                             | <b>Log Pond Sediments</b>                        | <b>Partially Controlled</b><br>- Area capped as part of successful interim action<br>- Cap enhancements to be included in final site cleanup to ensure long-term stability of cap edges   |
|                             | <b>Historic Dredge Disposal</b>                  | <b>Controlled</b><br>- Rigorous dredge material characterization and management protocols now required by regulation and permit for all dredging projects   |
|                             | <b>Chlor-Alkali Plant Discharges to ASB</b>      | <b>Controlled</b><br>- Chlor-alkali plant was closed and demolished by GP, with termination of wastewater discharges to the ASB.  |
|                             |  |   |
| <b>Phenolic Compounds</b>   | <b>Historic Pulp Mill Discharges to Waterway</b> | <b>Controlled</b><br>- NPDES Wastewater improvements implemented in the 1970s, including primary & secondary treatment, and termination of waterway discharges.<br>- Early remedial efforts completed in the Whatcom Waterway included sediment removal actions in 1974 |
|                             | <b>Pulp Mill Discharges to ASB</b>               | <b>Controlled</b><br>- Pulp mill and associated chemical plant were closed by GP, with termination of associated wastewater discharges to the ASB.  |
|                             | <b>Wood Waste from Log Rafting</b>               | <b>Controlled</b><br>- Cargo shipments of logs and wood products have been reduced, and additional regulatory and permit-required pollution controls apply to log/wood handling activities.   |
|                             | <b>Historic Sewer Outfalls</b>                   | <b>Controlled</b><br>- Sewage treatment and discharge improvements implemented in the 1960s and 1970s.  |
|                             | <b>Stormwater Discharges</b>                     | <b>Controlled</b><br>- Ongoing stormwater system upgrades to reduce/eliminate CSO events.   |
|                             |  | - No evidence of ongoing sediment impact in intermittent CSO area<br>- Enhanced stormwater management practices, permitting and monitoring.   |

**Table 8-1 Summary of Principal Contaminants and Sources**

| Principal Site Contaminants           | Principal Source(s)   | Source Control Status  |
|---------------------------------------|---|--|
| <b>Other Compounds</b>                | <b>Boatyard Wastes</b><br><br>(Copper, Zinc, TBT)                 | <b>Controlled</b>  |
|                                       |   | - Closure of early over-water boat lift formerly located adjacent to Colony Wharf site.  |
|                                       |   | - Enhanced stormwater controls and permitting at Colony Wharf site.  |
|                                       | <b>Creosoted Pilings</b><br>(PAH Compounds)                       | <b>Controlled</b>  |
|                                       |   | - Changes in materials use for new construction  |
|                                       |   | - Ongoing pile removal programs being implemented by Port, DNR and Ecology.  |
|                                       | <b>Cargo Spillage</b><br>(PAH Compounds, Wood Waste)              | <b>Controlled</b>  |
|                                       |   | - Reductions in Log/Wood/Chip handling   |
|                                       |   | - Changes in cargo handling practices  |
|                                       |   | - Proactive materials management planning for new cargos   |
|                                       | <b>Phthalate &amp; Nickel Sources</b><br>(I&J Waterway Site Area) | <b>Controlled</b>  |
|                                       |   | - Elimination of historic sources of these compounds (i.e., Olivine ore, historic plant fire)  |
|                                       |   | - Investigation & Cleanup of the I&J Waterway site under an Agreed Order and Ecology oversight   |
| <b>Contaminants at Adjacent Sites</b> |   | <b>Controlled</b><br>Actions at other waterfront sites coordinated under the Department of Ecology, these sites do not represent a current source control concern. |

**Notes:**

This table summarizes primary sources of sediment contamination. Secondary sources of sediment contamination (i.e., volumes of impacted sediment present at the site) are to be addressed as part of the final remedial action evaluated in the RI/FS.

Section 2 of the RI contains an overall history of the Whatcom Waterway site.

Section 6.1 of the RI includes a detailed discussion of site source control activities.

Table 8-2 Nature & Extent of Impacts

| Site Study Area    | Study Topics   | Principal RI Activities & Findings  | Quick Reference to Relevant RI Sections   |
|--------------------|--|---|---|
| Waterway Sediments | Assess current site lithology, including the impacts of historic dredging and shoreline development activities | Site lithology characterized through review of historic records, review of historic sediment borigns, and completion of extensive subsurface physical and chemical testing  | Section 3.1 includes a discussion of site lithology, with accompanying geologic cross-sections developed from subsurface explorations.                  |
|                    | Document the nature & extent of current impacts in the bioactive zone (surface sediments)                      | Surface sediment testing performed using chemical testing and whole-sediment bioassays  | Section 5.2 figures, tables and text summarize the results of chemical and bioassay testing.  |
|                    | Documentation the extent of natural recovery processes occurring at the site                                   | Natural recovery processes studied with cores and sediment traps, modeled quantitatively and then verified through direct observation of decreasing sediment concentrations | Section 6.2 documents natural recovery processes evaluated at the site. Changes in surface sediment conditiosn over time are documented in Section 5.2. |
|                    | Quantify the nature & extent of subsurface sediment impacts  | Core sampling used to directly assess the nature and extent of subsurface sediment impacts  | Subsurface sediment quality summarized in Section 5.3. Refer also to the cross-sections and the lithology discussion in Section 3.1.                    |
|                    | Assess potential dredge disposal properties of waterway sediments  | Dredge disposal suitability testing performed in support of the Feasibility Study   | Previous dredge material evaluations summarized in Section 7, and in Appendix H.  |
| Log Pond Sediments | Delineate surface & subsurface impacted sediments  | RI activities included surface and subsurface testing prior to implementation of Log Pond Interim Action  | Surface and subsurface sediment quality data are summarized in Section 5.2 and 5.3.   |
|                    | Monitor effectiveness of Interim Action and assess any potentially appropraite cap enhancements                | Effectiveness of Interim Action has been assesed through implementation of Year-1, Year-2 and Year-5 monitoring events  | The Year-5 Log Pond Monitoring report is attached as Appendix I. Proposed enhancements to the Log Pond cap are discussed in the site Feasibility Study. |
|                    | Assess the potential performance of in situ treatment technologies for application at the site                 | In situ treatment pilot test performed in support of the Feasibility Study  | Results of ECRT pilot testing are summarized in Section 7.  |
| ASB Areas          | Assess current site lithology, including the impacts of historic dredging and shoreline development activities | Site lithology characterized through review of historic records, review of historic sediment borings, and completion of extensive subsurface physical and chemical testing  | Section 3.1 includes a discussion of site lithology, with accompanying geologic cross-sections developed from subsurface explorations.                  |
|                    | Assess the volume and thickness of the ASB sludges   | Bathymetric and invasive physical testing used to quantify the volume of the ASB sludges  | Bathymetric data are summarized in Section 3.1 and accompanying figures. Physical testing data are summarized in Appendix C and Appendix D to the RI.   |
|                    | Assess the chemical Properties of ASB Sludges  | Core sampling used to document concentrations of mercury, phenoloic compounds and other contaminants in ASB sludges.  | Chemical properties of the ASB sludges are summarzied in Section 5.3 and the accompanying figures and tables, and in Appendix C.                        |
|                    | Evaluate the characteristics of the ASB berm materials   | Berm sand quality assessed through direct chemical and physical testing, to assess potential for reuse of these materials.  | Chemical properties of the berm sands are summarzied in Section 5.3 and the accompanying figures and tables, and in Appendix D.                         |
|                    | Quantify the characteristics of the sands underlying the ASB   | Chemical and physical testing performed for the sands underlying the ASB sludges  | Chemical properties of the berm sands are summarzied in Section 5.3 and the accompanying figures and tables, and in Appendix C.                         |
|                    | Assess the physical properties of the sludges relevant to site remedial decisions                              | Physical properties of the sludges assessed through physical and geotechnical testing, and during dewatering tests performed in support of the Feasibility Study.           | Geotechnical properties of ASB materials are included in Appendix C. Dewatering test results are summarized in Section 7, and in Appendix D.            |
| Starr Rock Area    | Nature & extent of historic dredge disposal area   | Area of dredge disposal documented through review of historic records, site bathymetric monitoring and delineation of sediment areas containing elevated mercury levels     | Disposal site location identified in Figure 3-1. Sediment quality data are summarized in Section 5.2 and in associated figures and tables.              |
|                    | Effectiveness of natural recovery  | Site monitoring has verified compliance with sediment standards (biological SQS and site-specific BSL)  | Current site data are summarized in Section 5.2 and in Figure 5-2.  |



Table 8-3 Fate & Transport Processes

| Fate & Transport Process | Principal Issues & Observations  | Summary of RI Findings   |
|--------------------------|--|--|
| Natural Recovery         | Deposition of clean surface sediments  | Gross & net deposition rates quantified with sediment traps and natural recovery cores   |
|                          |  | Reductions in contaminant concentrations documented and correlated to specific time signatures in sediment cores                           |
|                          |  | Consistent recovery pattern verified with core and grab sampling throughout site   |
|                          | Measurement of natural recovery rates  | Previous natural recovery studies by others<br>Predictive recovery modeling as part of 2000 RI/FS  |
|                          | Verification of recovery model outputs   | Measured reduction of surface sediment contaminant levels between 1996/1998 and 2002 sampling events                                       |
|                          |  | Observed contaminant reductions consistent with 2000 model outputs.  |
|                          | Limitations of natural recovery  | Areas of reduced natural recovery identified through physical and chemical mapping, and analysis of erosional properties.                  |
| Erosional Processes      | Reduced natural recovery in high energy, shallow-water areas   | Shallow-water, high energy areas with low natural recovery rates identified offshore of ASB  |
|                          | Redistribution of fine-grained sediments in nearshore areas  | Wind and wave energy analysis conducted as part of RI/FS activities to identify areas of potential significance                            |
|                          |  | Shoreline stability incorporated into Feasibility Study and remedial design evaluations  |
|                          | Shoreline infrastructure needs assessed in relation to navigation uses and shoreline/waterway geometry | Analysis of shoreline stability and potential future shoreline infrastructure needs incorporated into Feasibility Study                    |
| Navigation Dredging      | Impacts to waterway and ASB bathymetry   | Historic dredge contacts documented as part of site lithology  |
|                          | Periodic re-exposure of subsurface sediments if remaining within proposed dredge units                 | Potential future navigation dredging needs incorporated into Feasibility Study and remedial design evaluations                             |
|                          | Historic dredge disposal areas   | Extent of dredge disposal impacts quantified in Starr Rock area  |
|                          | Potential disposal options for future navigation dredging  | Dredge material characterizations incorporated into RI activities in support of Feasibility Study  |
| Bioturbation             | Formation of mixed bioactive zone  | Bioactive zone thickness measured to be 12 cm  |
|                          | Periodic deep sediment mixing  | Analaysis of potential deep mixing events conducted  |
| Propellor Wash           | Potential sediment erosion in navigation areas   | Propellor wash issues identified for evaluation as part of Feasibility Study and remedial design efforts                                   |
| Anchor Drag              | Periodic mixing of surface & subsurface sediments in anchorage areas                                   | Limited impact due to limited use of anchors within principal site areas (i.e., availability of dock moorage, alternative anchorage sites) |
|                          |  | Potential for periodic deep mixing evaluated for consideration during RI/FS and remedial design  |

Notes:

- Natural recovery and fate and transport processes are described in Section 6.2 and 6.3 of the RI report.
- Land use and navigation issues are discussed in Section 3.3 of the RI report.

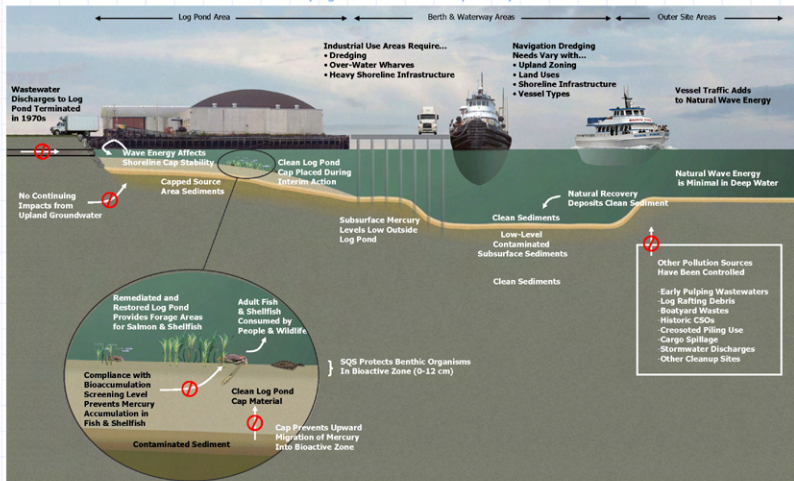
**Table 8-4 Exposure Pathways and Receptors**

| Receptor                    | Exposure Pathway  | Basis for Evaluating Protectiveness   |
|-----------------------------|---|---|
| <b>Benthic Organisms</b>    | Direct toxicity to benthic/epibenthic invertebrates   | Screening for areas of potential impact using SMS numeric standards   |
|                             |   | Verification using whole-sediment bioassays and SMS interpretive criteria   |
| <b>Human Health</b>         | Contaminant exposure through consumption of seafood containing bioaccumulated mercury and/or methylmercury            | Development of a site-specific BSL as part of 2000 RI/FS activities to identify sediment concentrations that will prevent significant bioaccumulation impacts |
|                             |   | Conservative application of BSL in site decision-making to ensure a substantial additional degree of protectiveness   |
| <b>Ecological Health</b>    | Exposure of higher trophic level wildlife (e.g., whales) through consumption of benthic organisms                     | BSL assessed to verify its protectiveness of potential wildlife exposures   |
|                             |   | Verification of BSL protectiveness through sediment bioaccumulation tests and seafood tissue monitoring   |
| <b>Other Considerations</b> | Cross-media transfers (e.g., contaminant leaching) and subsequent exposure to human health or environmental receptors | Contaminant mobility studies conducted in support of Feasibility Study and Remedial Design efforts  |
|                             | Direct contact of human health and ecological receptors at dredge disposal locations                                  | Applicable regulatory standards for dredge disposal scenarios evaluated as part of Feasibility Study  |

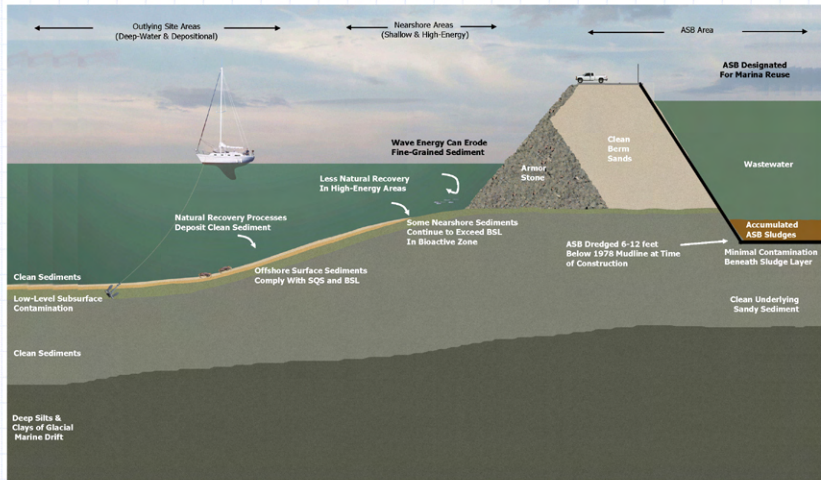
**Notes:**

Section 4 contains a summary of exposure pathways and receptors, and a discussion of the screening levels used to evaluate the protectiveness of site conditions under these exposure conditions.

**Figure 8-1**  
**Conceptual Site Model – Part 1 of 2**  
 (Log Pond and Waterway Areas)



**Figure 8-2**  
**Conceptual Site Model – Part 2 of 2**  
 (ASB and Outlying Site Areas)



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**Appendix A**  
**Pre-Remedial Design Evaluation Report (2003)**

**Appendix B**  
**Sediment Data Summaries from 2000 RI/FS**

**Appendix C**  
**2003 ASB Sampling Data**

**Appendix D**

**Results of 2004 Testing of ASB Sludges and Berm  
Sands**



**Appendix E**  
**Data and Regression Analyses from BSL**  
**Development**

**Appendix F**  
**Colony Wharf Sediment Sampling Report**

**Appendix G**

**Enrichment Ratio Summaries for Subsurface  
Sediments**

**Appendix H**  
**Previous PSDDA Suitability Evaluations**

**Appendix I**  
**Year 5 Log Pond Monitoring Report**